AN INSTRUMENTED FLIGHT TEST OF FLAPPING MICRO AIR VEHICLES USING A TRACKING SYSTEM

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Keywords: *Flapping Micro Air Vehicle (FMAV); Flight Test;Motion Capture Tracking System;Tracking Marker;Flight Performance Assessment*

1 Introduction

A flapping-type micro air vehicle(MAV) is one of the vehicles attracting the MAV engineers for its diverse capabilities such as agility, perching and even hover that are advantageous when performing missions in varying environments. While the flapping MAV has a history of research and development, it has considerably been relying on developers' trial and errors, and empirical skills. Particularly in test and evaluation phase of development which is crucial for the assessment and evolution of vehicle performance, much of it has been done by visual observation of the vehicle flight and the following subjective estimation.

This paper presents the procedure and resulting achievement of an instrumented flight test performed on the flapping MAVs that are being developed by the authors. Performed in an indoor flight test facility for the exclusive use of MAVs equipped with Vicon motion capture system[1] and tracking cameras, spatial position and orientation data were acquired from the flying vehicles with tracking markers attached. With their proper derivatives and investigation, a quantitative analysis was carried out for the assessment of vehicle performance parameters.

2 Test Details

2.1 Test Facility and Equipments

When it comes to flight or ground test of aircraft under development, people conventionally think of numerous sensors or gages, and connecting wires to data acquisition device. As this approach is virtually inapplicable to MAVs for their dimension and weight not equivalent to those testing tools, something completely different and novel is required to test and evaluate the performance of MAV.

The flight test facility(Fig.1) newly built in AFRL is its 2nd phase of total construction and for MAV test use only. Its capacity of visual motion capture system enables real-time vehicle flight data acquisition with the only addition of tiny and light retro-reflective markers to the vehicle. This feature led us to make an attempt to perform the flight test of the vehicles in the facility that the authors are developing together.

The brief principle of how the system works is shown in Fig.2. Because flapping-type MAVs are flying with wing motion that is more dynamic than other type MAVs such as rotary or fixed ones, data selection and interpretation along with good understanding of the limit of test equipment turned out critical.

2.2 Test Preparation and Execution

Three flapping MAVs in total were tested to look into the parametric characteristic of various sizes. Fig.3 shows one of them, of which wing span extends to 59cm. The wing spans of the others are 50cm and 39cm, respectively.

Various composite materials had been tried for manufacturing platforms, including glass/epoxy and carbon/epoxy. After going through the efforts of design optimization and weight reduction, carbon/epoxy batten, balsa core, nylon fabric and etc. were employed for constructing wing and fuselage.

In addition to the size, some other parameters of vehicle structure were included such as different

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
AUG 2011	**N/A**	**-**

4. TITLE AND SUBTITLE	
An Instrumented Flight Test Of Flapping Micro Air Vehicles Using A Tracking System	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Aeronautical Tech. Directorate, Agency for Defense Development, Daejeon, Korea**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADA555447. International Conference on Composite Materials (18th) (ICCM-18) Held in Seoul, Korea on August 22-26, 2011. U.S. Government or Federal Purpose Rights License, The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**SAR**	**4**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

stroke angle, landing gear and payload. Particularly the variable of stroke angle was selected to see its influence on the advance ratio.

Fig.4 indicates some of how the test was done and how it was displayed on the system. Basically the system recognizes a vehicle as the skeleton structure made out of tracking markers, and detects them during flight at designated sampling rate. Diverse maneuvers of straight and circular level flight(loiter), ground flapping, takeoff and landing, and their combination were tried to obtain performance data. Some pictures taken during the test are shown in Fig.5 through Fig.7.

2.3 Test Data Investigation and Assessment

The raw data obtained from the tracking system are real-time spatial position and orientation of a vehicle. Through proper filtering and selection of the raw data, and applying derivatives or editing them for other parameters such as velocity or angular rate, the flight performance of the vehicle can be assessed.

Since flapping-type MAVs fly with more dynamic wing motion compared to the other type of MAVs, such as rotary or fixed ones, data selection and interpretation along with good understanding of the limit of test equipment turned out to be critical.

Even though the facility was surrounded by as many as 60 cameras with sampling rate up to 100 Hz, some data loss or signal spike occurred due to the relative motion between wing markers originated from wing flexibility and intense dynamic flapping movement of the vehicle.

Due to the intrinsic dynamic flight characteristic of the vehicle, it was not easy to fly the vehicle to follow the designated clean maneuver. Even if you want to know how fast your vehicle travels in the air and try to test the straight level flight, maintaining the uniform altitude is impossible due to the inevitable body oscillation. Fig.8 illustrates one of the test results on the comparison of wing and fuselage height during straight level flight. When it couples with manual error when the vehicle is controlled by a remote control with a transmitter, some can argue it is no longer straight level flight in conventional way. However, since this ‘intrinsic’ character is also found in natural flyers’ flight such as birds, it is reasonable to set the reference different from the numerical standard, but on the nature standard discovered by experience. The authors are concurrently making efforts to develop the autopilot subsystem to enable the vehicle fly by programmed commands which will help minimizing artificial error. It is also expected accordingly to assess better and precise performances of vehicle in the next flight test.

Ground flapping test was used for validating the Vicon tracking data. The method is comparing the flapping frequency measured from the tracking data with the captured video from surveillance cameras installed on the wall of test facility. The frequency calculated from Fig.9 coincided with the frequency from the video, at the value of 10 Hz. Other test result of straight and circular level flight, such as velocity and trajectory(Fig.10,11) also turned out to be reasonable. Some discrepancies were included in the result due to the fact that the flights were manually controlled as mentioned at the early part of this paper.

One of parameters we paid attention to was advance ratio[2], which is defined as Eq.1 and gives the idea of if the vehicle flies in steady or unsteady flow regime, and then if it has enough thrust and flying efficiency as intended in design phase. In the equation, V, b, Φ, and f are forward flight speed, flapping angle, wing span, and flapping frequency, respectively.

Some of the data results are presented in Tab.1. The breakpoint between quasi-steady and unsteady flow is defined at $J=1$. For $J>1$ the flow can be considered quasi-steady while $J<1$ corresponds to unsteady flow regime[2]. Most insects operate in the unsteady regime, while many birds fly in quasi-steady or steady regime. Insects fly at relatively higher flapping frequency to produce wing tip vortex and obtain lift in completely unsteady airflow. On the other hand, birds fly at lower flapping frequency as they use air current. To make this possible, birds fly by gliding, soaring and even soaring. These kinds of flights, peculiar to some birds, are possible by morphing the wing using their muscle and articulation. Since the wing mechanism of the present vehicles is similar to that of insects rather than birds, the flight resembles the flight of insects, although the vehicles are bird-size. Thus, the advance ratio of the vehicles stays below one.

3 Conclusion

Instrumented flight test of different vehicles using a tracking system was performed for numerical performance analysis and the assessment of the flight. Practical test procedures and methods were employed to obtain reasonable test results out of raw test data. It is concluded that the test metrics attempted in the present study is applicable to the test and evaluation of flapping MAVs. Thus, this testing method will be useful for the development of future MAVs.

$$J=\frac{V}{\frac{1}{2}b\times 2\Phi\times 2f} \tag{1}$$

Fig.1. MAV flight test facility

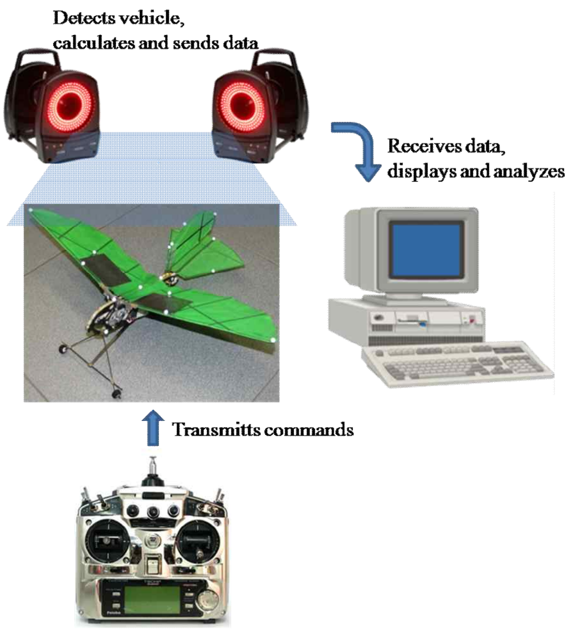

Fig.2. Schematic of visual tracking system

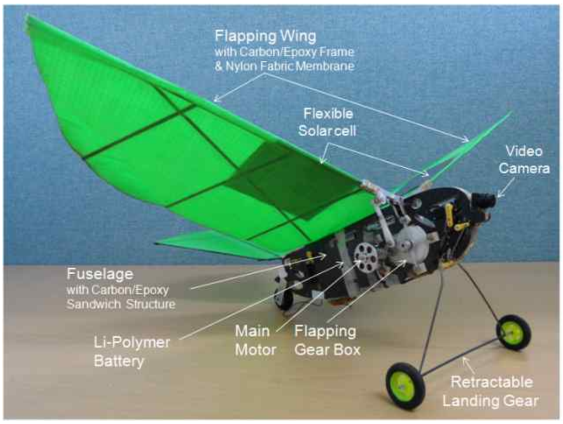

Fig.3. Flapping MAV with 59cm span tested

Fig.4. Vehicle with markers on and Vicon display

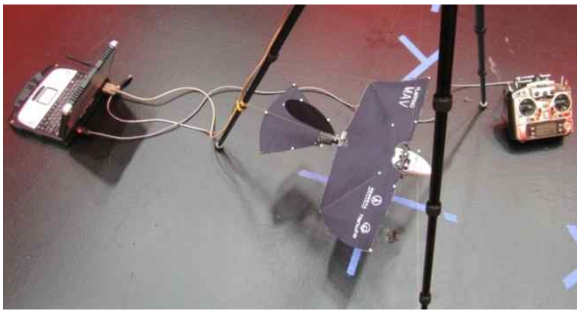

Fig.5. Ground flapping test

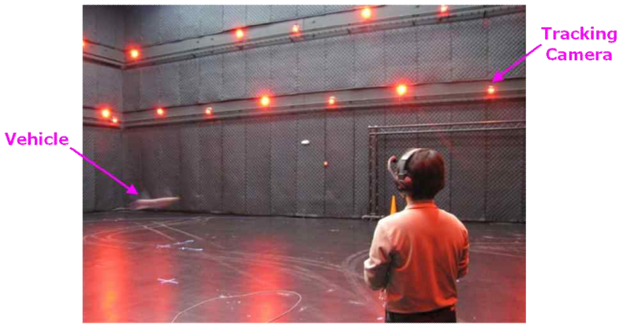

Fig.6. Circular level flight test

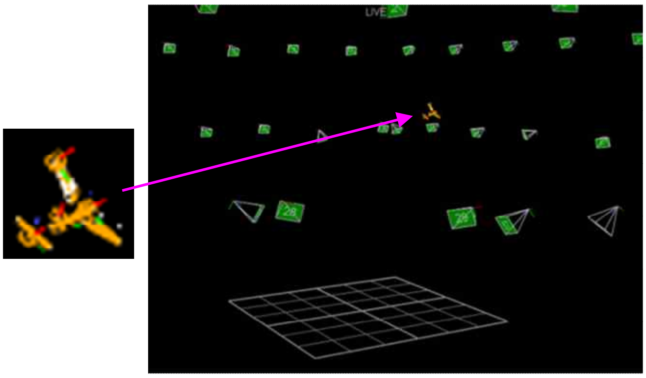

Fig.7. Real-time display in tracking system

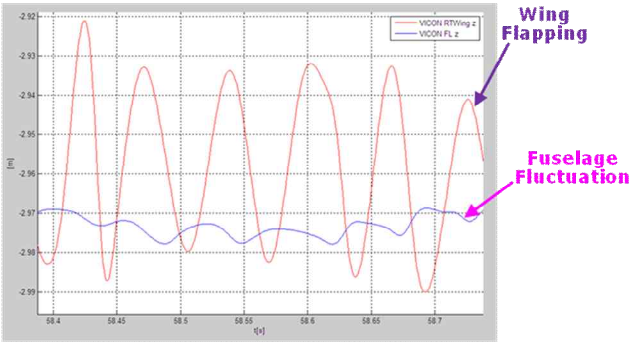

Fig.8. Body fluctuation during wing flapping

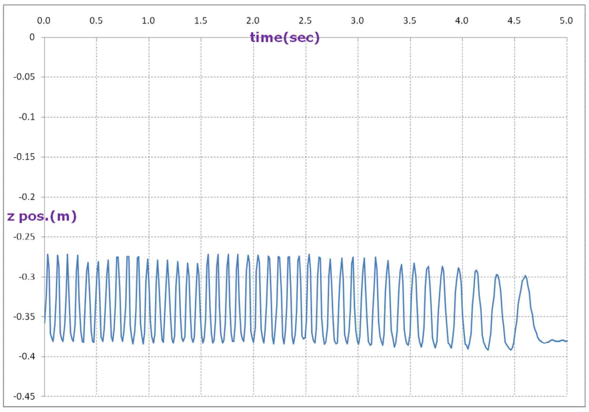

Fig.9. Ground flapping frequency

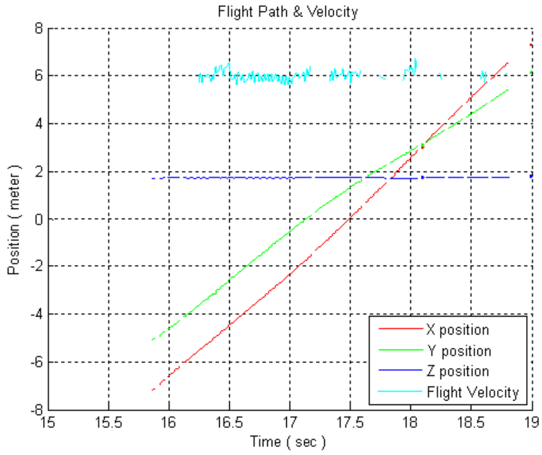

Fig.10. Forward velocity in straight flight

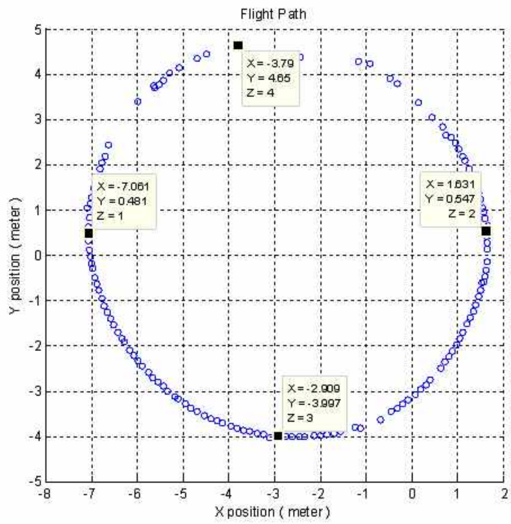

Fig.11. Trajectory in circular flight

θ	Stroke Angle	deg	25	30	35
f	Frequency	Hz	20.5	19.5	18
b	Wing Span	m	0.5	0.5	0.5
V	Velocity	m/s	5	4.5	5
J	Advance Ratio	-	0.559	0.441	0.455

Tab.1. Advance ratio with wing span variable

References

[1] Vicon Motion Systems, http://www.vicon.com

[2] Steven Ho, et al. "Unsteady aerodynamics and flow control for flapping wing flyers". *Progress in Aerospace Sciences 39*, pp 635-681, 2003.